COURSE 225

HEAT & THERMODYNAMICS

MODULE 4

TURBINE WITH REHEAT

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Heat & Thermodynamics

MODULE 4

TURBINE WITH REHEAT

Course Objectives

1. Given a set of conditions, a calculator and steam tables, you will be able to calculate values of steam flow, pressure temperature and moisture content at major points through the turbine cycle.

2. You will be able to explain how the pressure and temperature vary through a turbine as the load increases from 0% to 100%, assuming constant vacuum.

Enabling Objectives

1. Given a set of conditions applicable to a steam turbine, with reheat, you will be able to sketch a Mollier diagram and illustrate the overall turbine process.

TURBINE WITH REHEAT

This module is an extension of the principles that we examined in Module 3. We will continue to use the Mollier diagram to illustrate the process and then use the steam tables to calculate the required values.

Before we plot the overall process steps on a Mollier diagram, it is of benefit to consider what changes are taking place in the turbine process at any point.

High Pressure Turbine

Steam Flow

If there is no extraction steam, the flow in and out of the turbine remains unchanged.

Enthalpy

The steam flows through the turbine at high speed and consequently there is an insignificant change in enthalpy of the steam due to heat loss through the casing. However, the turbine is a device whereby we can exchange heat energy for mechanical work. It follows that the enthalpy of the steam leaving the high pressure turbine will have a lower value than at the inlet. This lower enthalpy may be measured in terms of a lower temperature and pressure. Additionally, the quality of the steam will have deteriorated as some of the saturated steam condenses in the expansion process, producing wet steam.

Main Moisture Separator

This device removes the majority of the moisture that appears in the steam at the exhaust of the high pressure turbine. The temperature of the steam is not altered as the moisture is mechanically removed. In practice there is a slight pressure drop across the main moisture separator which will reduce the temperature by one or two degrees.

The steam flow out of the moisture separator is not the same as that entering the moisture separator. The reduction in mass flow is equal to the change in moisture content within the main moisture separator, eg, a moisture separator reduces the moisture level in steam at 1.8 MPa(a) from 12% to 4%. Determine the change in mass flow.

As a first approximation let us consider that 12% of the fluid was initially moisture and this was reduced to a final figure of 4%. Thus, 12% - 4% = 8% of the mass flow must have been removed to achieve this new quality.

For a more accurate calculation we must perform a mass balance across the moisture separator. Consider the sketch below where $\dot{m}$ represents mass flow and q steam quality.

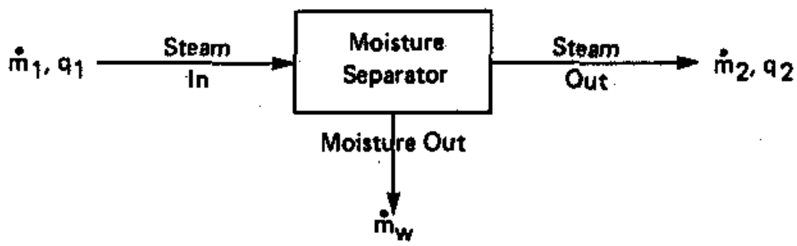


Fig. 4.1

For a total mass flow balance $\dot{m}_1 = \dot{m}_2 + \dot{m}_w$. However, if we consider only a water mass balance $\dot{m}_1(1-q_1) = \dot{m}_2(1-q_2) + \dot{m}_w$.

Combining these two equations enables us to calculate $\dot{m}_w$, the mass flow rate of water extracted from the steam

$$\dot{m}_1(1-q_1) = (\dot{m}_1 - \dot{m}_w)(1-q_2) + \dot{m}_w$$

which reduces to

$$\dot{m}_w q_2 = \dot{m}_1 q_2 - \dot{m}_1 q_1 \qquad \text{or} \qquad \dot{m}_w = \dot{m}_1 \frac{q_2 - q_1}{q_2}$$

The enthalpy of the steam increases, not because heat energy was added but because the degrading moisture was removed and the average enthalpy increased while the overall steam flow decreased.

Reheater

The reheater raises the enthalpy of the steam leaving the main moisture separator prior to its admission to the low pressure turbine.

The pressure of steam leaving the reheater does not increase although the enthalpy and temperature have increased due to the addition of heat energy.

There is no change in the steam flow in and out of the reheater, there is no significant moisture to remove nor is there any steam extracted from the reheater.

Low Pressure Turbine

There is always steam extracted for feedheating from the low pressure turbine so the exhaust flowrate into the condenser will be less than the flowrate into the turbine.

As in the high pressure turbine, the loss of enthalpy through the casing is insignificant and the major enthalpy drop is due to the conversion of heat energy into mechanical work. This may be seen by a lowering of pressure and temperature.

As the heat energy is converted into mechanical work, the quality of the steam deteriorates as the moisture level increases.

Before we proceed to examine any further, try the following exercises and check your responses at the back of the course.

Q4.1 The steam flow entering a moisture separator is 700 kg/s. The steam has an initial moisture content of 9.4% and has a final dryness fraction of 99.6%. Calculate the flowrate of steam from the moisture separator.

Q4.2 Show whether the following parameters increase, decrease or remain the same for the following sections of turbine unit with feedheating:

(a) High Pressure Turbine
(b) Moisture Separator
(c) Reheater
(d) Low Pressure Turbine

Item	Enthalpy	Temperature	Pressure	Flowrate	Steam Quality

Note: Ignore any pressure drop through the moisture separator and reheater.

* * * * *

Let's examine a question which reflects the main points of our discussion.

900 kg/s of steam exits the HP stage of a turbine at 1.5 MPa(a) with a moisture content of 10%. This steam passes through a moisture separator which removes its total moisture content and then passes through a reheater. There is no significant pressure drop in the moisture separator and reheater.

The secondary side of the reheater operates at 4.5 MPa(a) and is fed with 65 kg/s of saturated steam from the boiler. The condensed steam which results, leaves the reheater at saturation temperature.

(a) (i) Draw a schematic diagram of the process described above showing the following parameters at each step of the process:

- flow
- pressure
- moisture content.

(ii) Determine the steam temperature at the exit of the reheater, showing clearly how you proceed.

(b) The steam enters the LP stages of the turbine where it expands isentropically (ie, with constant entropy), the exhaust pressure being 10 kPa(a). Calculate the moisture content of the steam at the LP exhaust, showing clearly how you proceed.

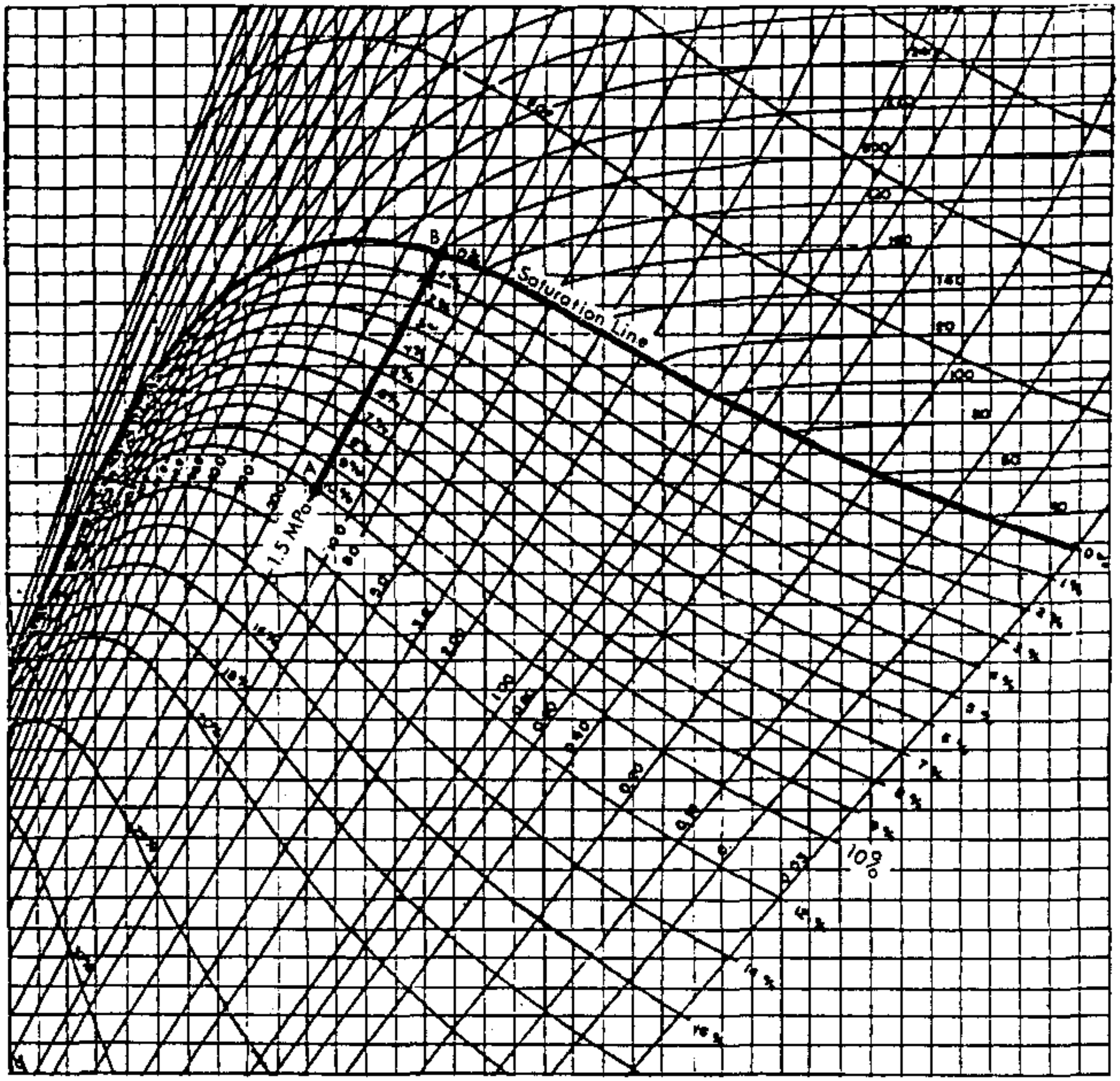
The information presented may initially seen overwhelming but with a systematic approach, we should be able to satisfy all the requirements of the question.

It is very useful to have a pictorial representation of the process. Question (a) (i) asks for a schematic diagram for the process and it would appear preferable to sketch the process itself; at least this way, there is some reinforcement of the process sequence which is occurring.

Using the Mollier diagram we can illustrate the total process sequence.

Moisture Separator

The moisture is removed at constant pressure. On the Mollier diagram this will be represented by moving up the 1.5 MPa(a) constant pressure line from 10% moisture to the saturation line, ie, 0% moisture.



Enthalpy, kJ/kg

Entropy, kJ/kg °C

Fig. 4.2

Point A is the exhaust from the high pressure turbine and the inlet to the moisture separator.

At Point A
1. Flowrate is 900 kg/s.
2. Pressure is 1.5 MPa(a).
3. Moisture content 10%.

Point B is the exhaust from the moisture separator and the inlet to the reheater.

At Point B

1. Flow rate is reduced by 10% due to the removal of the moisture. Thus flowrate
   flowrate = 0.9 x 900 = 810 kg/s.
2. Ignoring the pressure drop in the moisture separator, there is no change in pressure.
3. The moisture content is 0%, ie, the steam is now saturated at 1.5 MPa(a).

<u>Reheater</u>

The reheater adds heat at constant pressure so we can continue up the 1.5 MPa(a) constant pressure line to some new point as determined by the heating steam supply to the reheater.

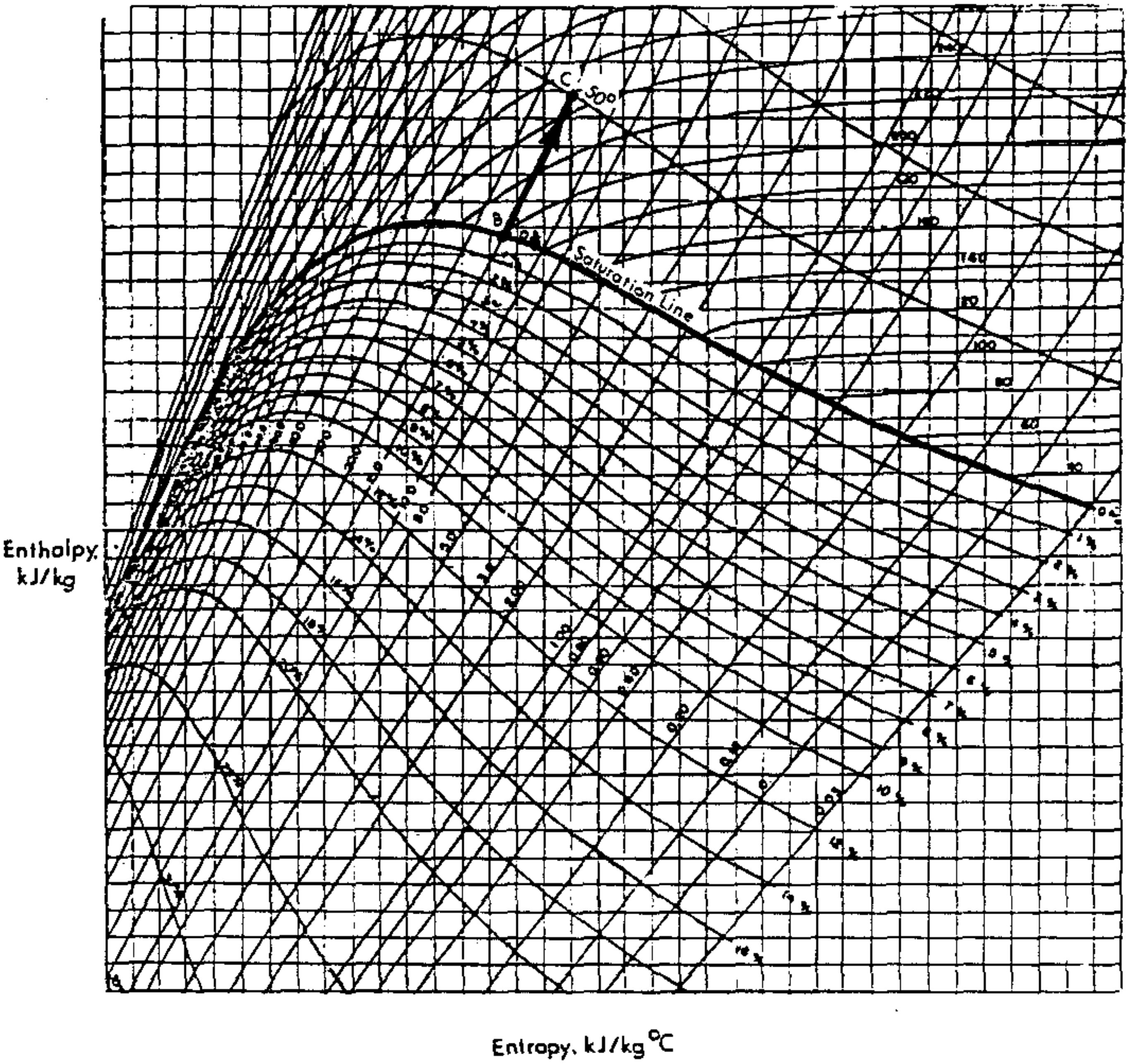


Fig. 4.3

Point C is the exhaust from the reheater and is also the inlet to the LP turbine.

At point C flowrate is the same as at B = 810 kg/s. Pressure is 1.5 MPa(a). Moisture content is 0% because the steam is superheated.

If we want to tidy this up and present a complete picture, we can sketch the diagram and complete a table as shown below.

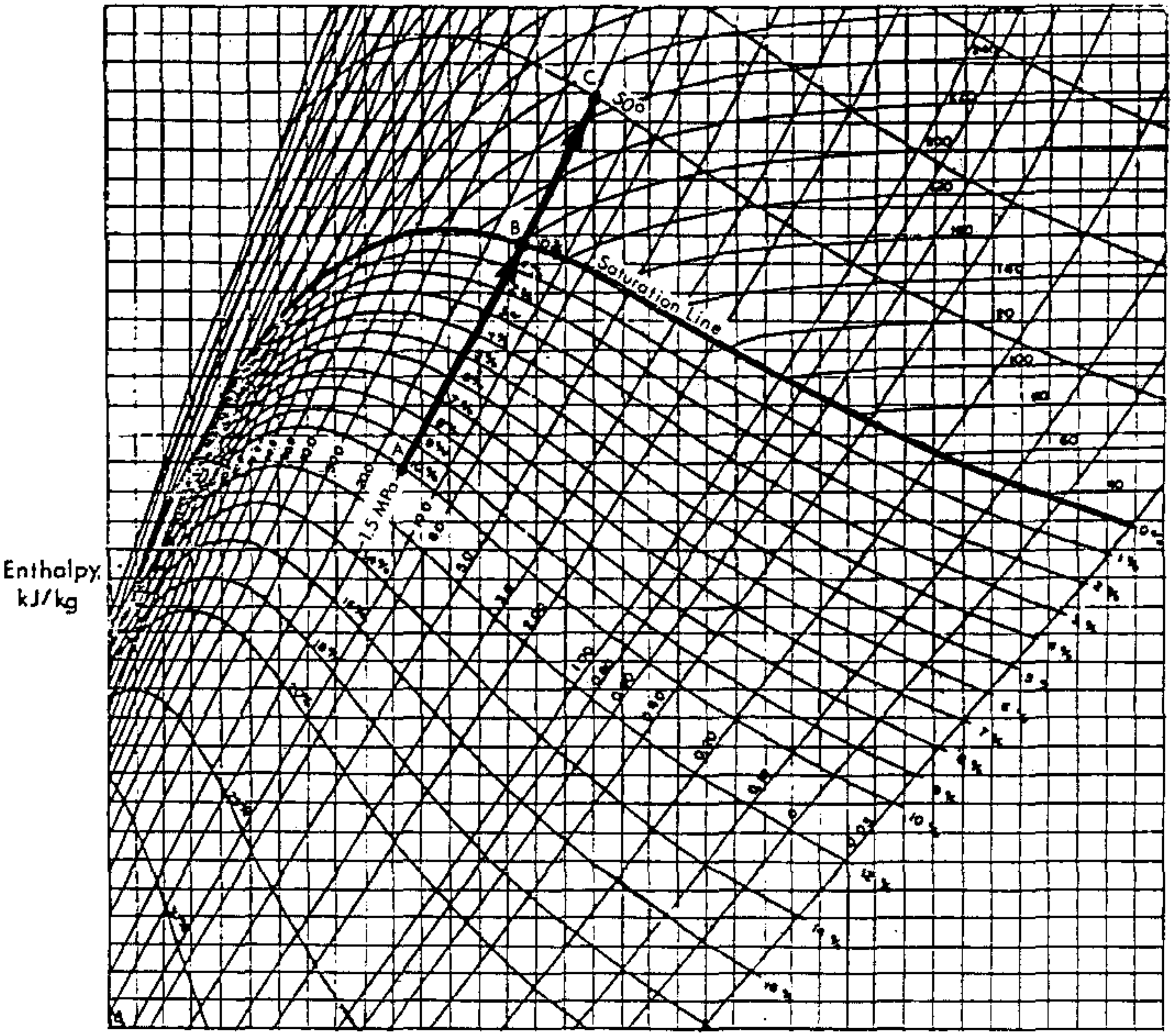


Fig. 4.4

Point	Flow	Pressure	Moisture
A	900 kg/s	1.5 MPa(a)	10%
B	810 kg/s	1.5 MPa(a)	0%
C	810 kg/s	1.5 MPa(a)	0%

Section (a) (ii) of the question asks us to determine the temperature of the steam leaving the reheater. There is no quick method of determining the temperature of the superheated steam. We have to calculate the amount of heat added to the process steam and then use steam tables to establish the temperature. The steam temperature changes with the addition of heat because it is superheated.

The basic approach to the reheater heat exchange is that the heat lost by the heating steam equals the heat gained by the process steam.

Heat Lost by the Heating Steam

The steam feeding the reheater is saturated steam and the condensate is not subcooled. The heat which has been removed from the heating steam is therefore the latent heat of vapourization at 4.5 MPa(a). We can see this clearly on the Temperature/Enthalpy diagram.

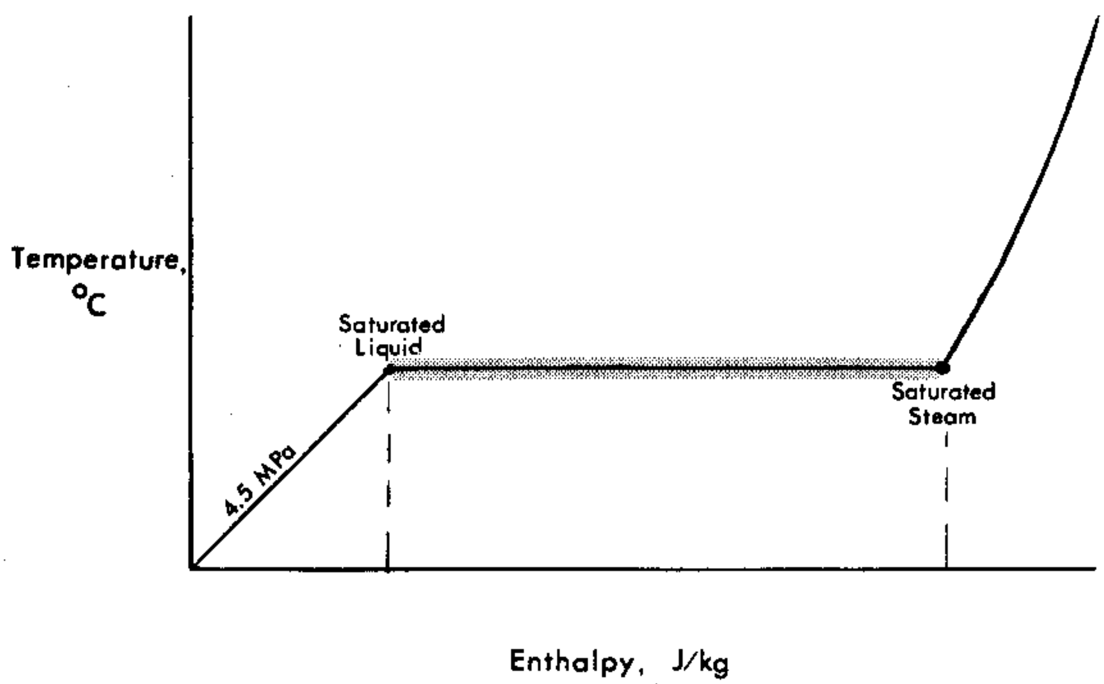


Fig. 4.5

The heat lost by the steam is the product of the mass-flow and the change in enthalpy. The decrease in enthalpy at 4.5 MPa(a) was from saturated steam h_g to saturated liquid h_f which is h_{fg}, the latent heat.

Mass Flowrate 65 kg/s

h_{fg} @ 4.5 MPa(a) = 1675.6 kJ/kg.

Thus heat lost = 65 x 1675.6 = 108,914

kg/s x kJ/kg = kJ/s.

This heat is gained by the process steam.

Using heat lost = heat gained, we can determine how much heat has been picked up by each kilogram of process steam.

Heat gained = process mass flowrate x increase in enthalpy. Heat gained = 108,914 kJ/s. Process mass flowrate through reheater = 810 kg/s. Increase in enthalpy is unknown.

Substituting

108,914 = 810 x increase in enthalpy.

Increase in enthalpy = $\frac{108,914}{810}$

= 134.5 kJ/kg.

The increased enthalpy is the enthalpy of the saturated steam at 1.5 MPa(a). h_g + 134.5 kJ/kg.

From tables h_g = 2789.9 kJ/kg.

New enthalpy = 2789.9 + 134.5 kJ/kg

= 2924.4 kJ/kg.

We must use the superheated steam tables at 1.5 MPa(a) to determine the temperature of the steam possessing the enthalpy of 2924.4 kJ/kg.

At 1.5 MPa(a) which is 15 bar, the enthalpy of the superheated steam is 2924 kJ/kg when the steam temperature is 250°C.

So the temperature of the steam leaving the reheater is 250°C.

Part (b) of this question is designed to see if you can calculate the quality of the steam using the entropy values as we did in Module 3.

Again a diagram is an asset and the process may be illustrated on a Mollier diagram, starting from the exit from the reheater which is the inlet to the low pressure turbine.

You should realize that if you made a mistake in calculating the temperature of the superheated steam in the previous section, then your answer to this section will also be incorrect even though you use the correct procedure.

The steam in the low pressure turbine expands isentropically, that is, at constant entropy. This is represented by a vertical line on the Mollier diagram. The line runs from the temperature of 250°C on the constant pressure line of 1.5 MPa(a) down until it strikes the constant pressure line of 10 kPa(a) as shown on the diagram.

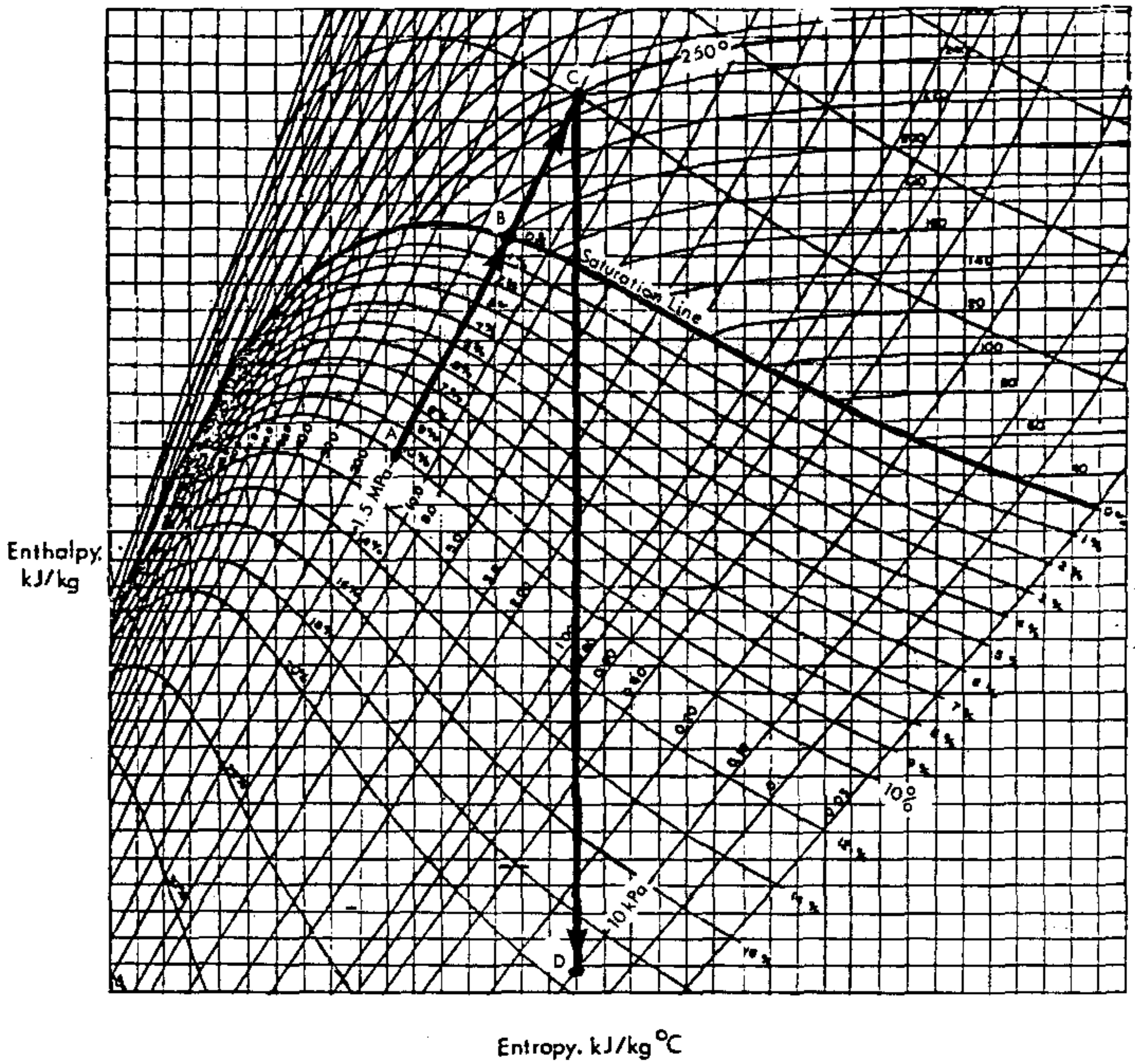


Fig. 4.6

The section on the diagram CD represents the isentropic expansion in the low pressure turbine.

We are asked to calculate the value of the moisture at point D and we will do this using the value of entropy which for this process is constant.

Using the superheated steam tables, we can look up the value of entropy at 1.5 MPa(a) and 250°C.

The value of entropy is 6.710 kJ/kg°C.

We know that this value remains constant throughout the expansion process down to 10 kPa(a).

We know that we have wet steam at 10 kPa(a) because the question tells us so. The entropy of the wet steam is found in exactly the same way as we find enthalpy.

Take the entropy of the liquid at 10 kPa(a).
$S_f = 0.6493$ kJ/kg°C. (10kPa(a) = 0.10 bar).

Now take the entropy from liquid to vapour at 10 kPa(a).
$S_{fg} = 7.5018$ kJ/kg°C.

The actual entropy value of the wet steam depends upon the quality 'q' and is found using $S = S_f + qS_{fg}$.

We know S because that stays constant and the initial condition allowed us to determine that value. We have looked up S_f and S_{fg} - the only unknown is the dryness fraction or quality 'q'.

Substituting the values into $S = S_f + S_{fg}$, we get
$6.710 = 0.6493 + q \times 7.5018$ kJ/kg°C,

thus $6.0607 = q \times 7.5018$

thus $q = \frac{6.0607}{7.5018}$

$= \underline{80.8\%}$.

This represents the vapour in the mixture, the moisture content is 1 - 0.808 = 0.192, or <u>19.2% moisture</u>.

This may appear to have been a lengthy process but you should realize that we have looked at a lot of detail, some of which you will have used on previous occasions.

The following examples are designed to reinforce the procedure we have just been through. Compare your answers to those at the end of the course.

Q4.3 Steam flows at 500 kg/s into a moisture separator. The steam has a dryness fraction of 88% and is at 1.0 MPa(a).

The moisture separator removes all of the moisture. The steam then enters a reheater where the heating steam is supplied at a pressure of 3.5 MPa(a) and a flowrate of 30.3 kg/s. The heating steam is saturated and the condensate is not subcooled. (Ignore any pressure drop through the moisture separator or reheater.)

(a) Sketch a diagram of the process and list the values of flow, pressure and moisture content at each step.

(b) Calculate the temperature of the steam leaving the reheater - show clearly how you proceed in the answer.

Q4.4 800 kg/s of steam enter a moisture separator at a pressure of 1 MPa. The moisture content is 13% at the inlet to the separator. Saturated steam leaves the moisture separator. The steam passes to a reheater using heating steam which is saturated at 3 MPa and which becomes subcooled by 6.8°C. The flowrate of heating steam is 41.5 kg/s.

Sketch the process on a Mollier diagram and determine the process steam temperature from the reheater. (Ignore any pressure drop in the moisture separator or reheater.)

Q4.5 Steam at 2 MPa(a) enters a low pressure turbine at 250°C. The steam expands isentropically and is exhausted to the condenser at 6 KPa(a).

Sketch the process on a Mollier diagram and calculate the moisture content of the steam leaving the low pressure turbine.

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Turbine Pressure and Temperature Gradients

Under operating conditions the steam generator supplies steam to the turbine at a nominal pressure of 4 MPa(a). The steam is saturated and exists at the saturation temperature of 250°C.

The turbine exhausts wet steam to the condenser operating at a nominal pressure of 5.6 kPa(a). Again this is a saturation condition and the temperature of the exhaust steam from the turbine will be t_s at 5.6 kPa(a), ie 35°C.

No matter what happens in the turbine, the steam supply will be at 4 MPa(a), 250°C and the exhaust steam will be at 5.6 kPa(a), 35°C.

Consider the startup condition where the ESV's are shut, the turbine is on turning gear and the condenser is at its normal operating pressure of 5.6 kPa(a)

Q4.6 What do you know about the pressures in the low pressure turbines, reheater, moisture separators and high pressure turbine in this start up condition. Check your answer at the end of the course.

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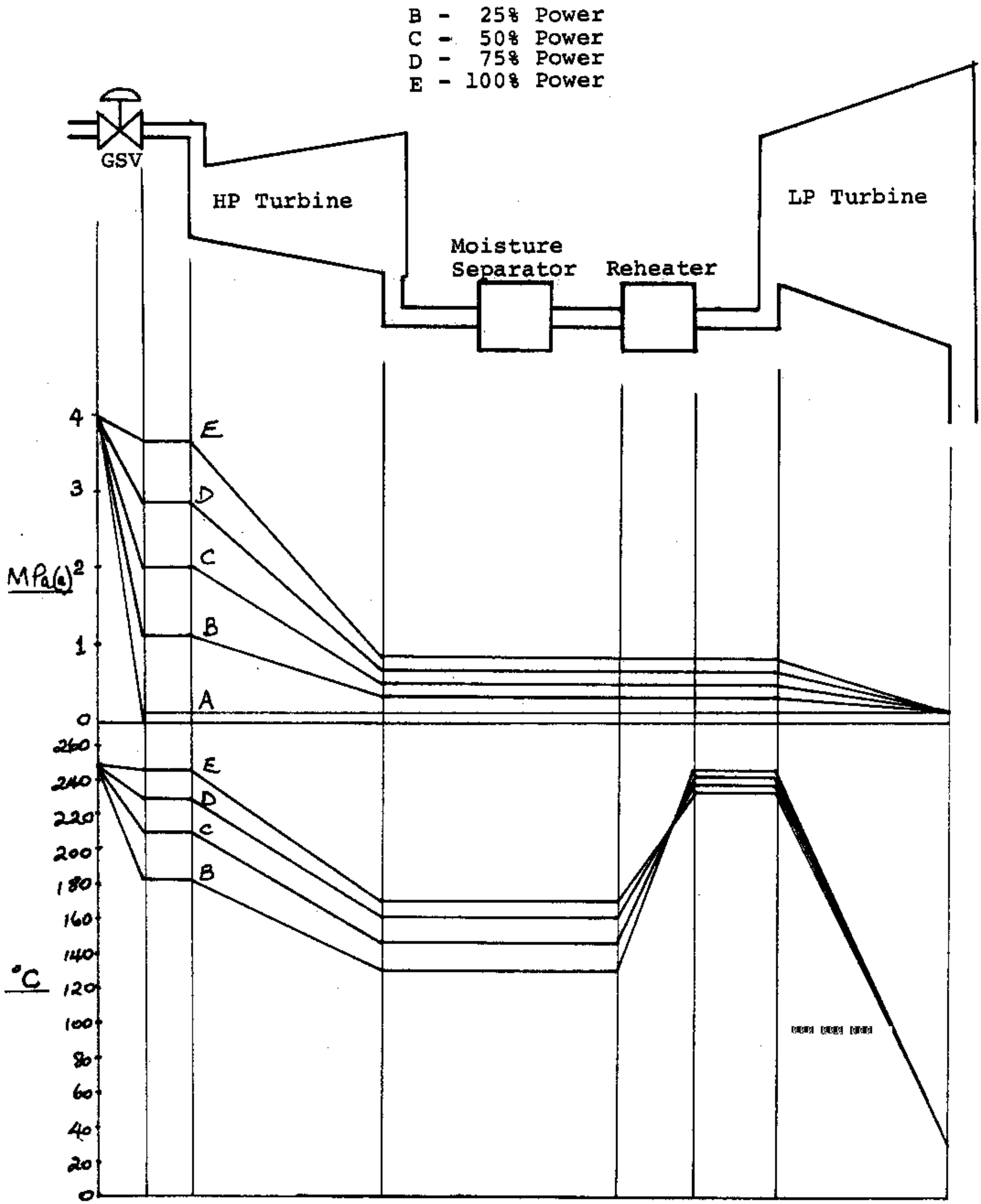

Fig. 4.7

Note: Actual pressure drops through the turbine will be non linear.

The condition just described is illustrated on the diagram by line A. You can see at this point that the pressure upstream of the ESV/GSV is 4.3 MPa(a) whilst downstream the pressure is 5.6 kPa(a).

Q4.7 Steam at 4 MPa(a) passes through open ESV's and leaks past tripped GSV's into the high pressure turbine. The condenser pressure is 10 kPa(a). What is the temperature of the steam in the high pressure turbine.

Check your answer at the end of the module.

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Suppose we have now run the turbine up to speed, synchronized and applied 25% load to the generator. In this situation the GSV's are open a small amount to admit slightly more than 25% full load steam flow. (At lower power less work is available per kg of steam due to throttling.)

This condition may be seen illustrated by line B on the diagram.

The pressure drop across the GSV is roughly 2.8 MPa so that the inlet pressure to the turbine itself is around 1.2 MPa(a). The saturation temperature corresponding to 1.2 MPa(a) is 188°C. The actual temperature at which the steam is entering the high pressure turbine is slightly higher due to superheat supplied by the throttling action of the GSV.

If the turbine is "cold" this does not present a problem but if the turbine is "hot" the admission of this low temperature steam will drastically cool the turbine and create high thermal stresses. This is the reason why block loading is employed for hot startup, to increase the steam temperature in the high pressure turbine casing to a value where no cooling occurs.

The change of inlet steam temperature of the turbine with increased GSV opening may be clearly seen from the temperature curves where the inlet temperature rises from about 188°C at 25% load to 250°C at 100% load.

From the same series of temperature lines you can see also that the HP turbine exhaust temperature is increasing as the load increases. The exhaust temperature rises from 133°C at 25% load to 175°C at 100% load.

It is interesting to note that as the power on the turbine increases the temperature of the process steam, leaving the reheater, falls from 250°C to 239°C.

Q4.8 Why do you think the temperature of the process steam leaving the reheater, is highest at the lowest power levels?

Check your answer at the end of the module.

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MODULE 4 - ANSWERS

Q4.1

The initial moisture content was 9.4% and the final moisture content was 0.4% (100 - 99.6 = 0.4%, you shouldn't have been caught here). This corresponds to initial steam quality of 90.6% and of course a final quality (as given) of 99.6%.

Using the formula developed by doing a mass balance across the moisture separator

$$\dot{m}_w = \dot{m}_1 \frac{q_2 - q_1}{q_2}$$

$$= 700 \times \frac{0.996 - 0.906}{0.996}$$

$$= 63.3 \text{ kg/s}$$

The flowrate of steam from the moisture separator will be the difference between steam flow into the separator and the moisture removed, ie, 700 kg/s - 63.3 kg/s = 636.7 kg/s.

Q4.2

(a) High Pressure Turbine

The enthalpy will decrease as some of the heat energy is converted into work.

The temperature and pressure will decrease as the enthalpy is reduced. The flowrate will be reduced only if steam is extracted for feedheating. In this case, we will ignore steam extracted from HP turbine. The steam quality decreases as more work is produced from the steam.

(b) Moisture Separator

The enthalpy of the steam will increase as the low enthalpy liquid is removed.

Ignoring the pressure drop, the pressure will remain constant.

The temperature of the steam will remain constant while the moisture is being removed.

The flowrate of steam from the moisture separator will be less than that at the inlet due to the removal of moisture. If steam is extracted from the moisture separator for feedheating, then this would also be taken into account when determining the new flowrate value.

The steam quality increases as the moisture is removed and the steam moves closer to the saturation condition.

(c) Reheater

The enthalpy of the steam increases significantly in the reheater and the final steam has approximately 60°C of superheat.

Ignoring the pressure drop in the reheater the pressure remains constant.

The temperature of the steam increases to a value approximately 60°C above t_s at the pressure in the reheater.

The mass flowrate through the reheater will remain constant since there is no extraction of steam.

The steam quality is raised from around 0.5% moisture to approximately 60°C of superheat.

(d) Low Pressure Turbine

The enthalpy decreases as work is extracted from the steam.

The temperature and pressure fall with the decreasing enthalpy.

The flowrate decreases due to the steam extracted for feedheating.

The steam quality decreases due to the condensation produced by the reduction in enthalpy.

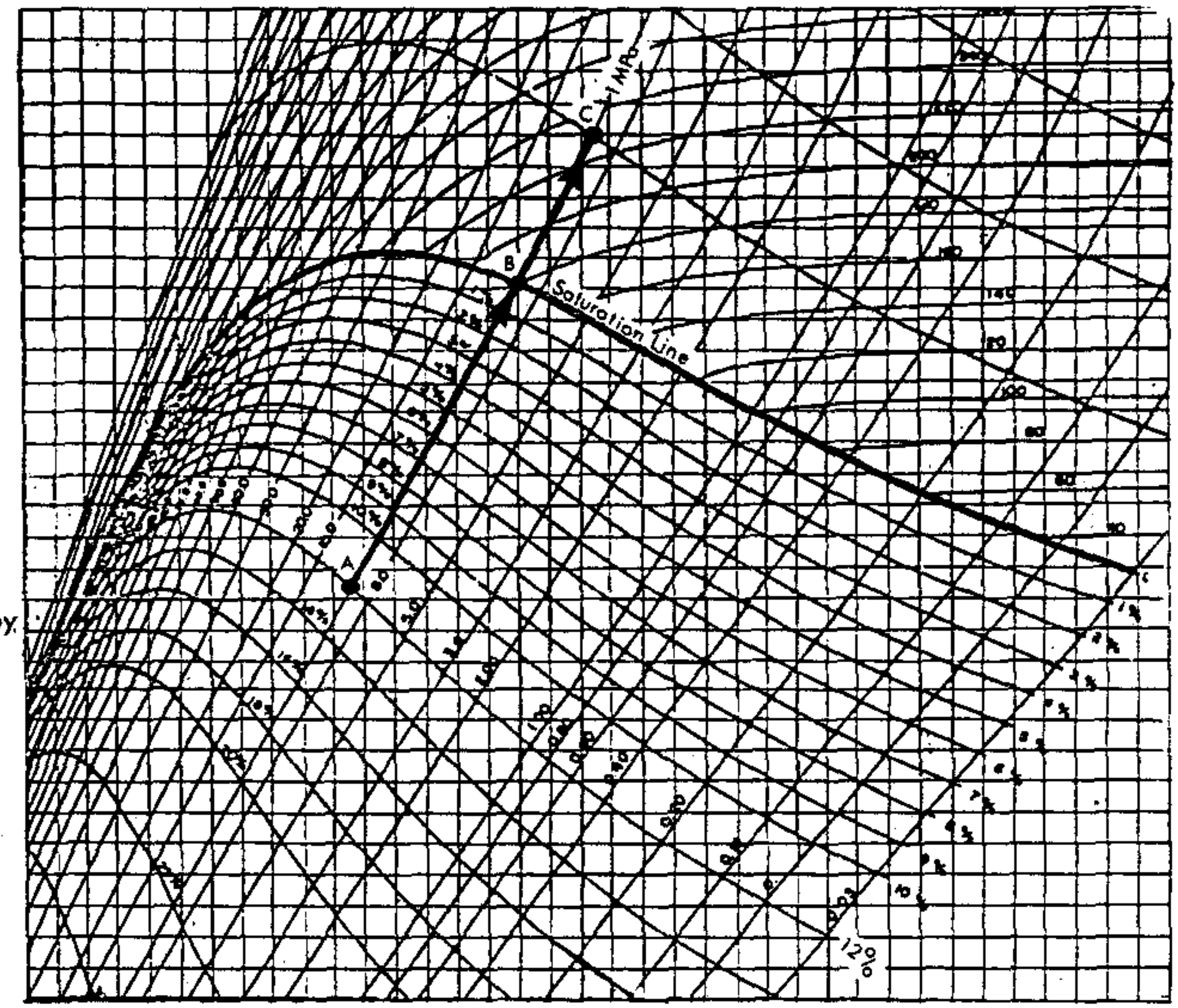
Item	Enthalpy	Temp.	Pressure	Flowrate	Steam Quality
HP Turbine	Decrease	Decrease	Decrease	Same	Decrease
Separator	Increase	Same	Same	Decrease	Increase
Reheater	Increase	Increase	Same	Same	Increase
LP Turbine	Decrease	Decrease	Decrease	Decrease	Decrease

Q4.3

In this question we do not have any turbine expansion after the reheat. Before doing any calculations, it is worth sketching the process so that there is a visual reference available as you work through the problem.

The process steam pressure is 1 MPa(a) and moisture separation to provide saturated steam, together with the reheating, both take place at constant pressure. On the Mollier diagram the process follows the constant pressure line upwards from the constant moisture line at 12% moisture.

Entholpy, kJ/kg



Entropy, kJ/kg°C

Fig. 4.8

Looking at the process points A, B and C, we can list the known values of pressure, flowrate and moisture content and calculate the unknowns.

Point	Moisture	Flowrate	Pressure
A	12%	500 kg/s	1 MPa
B	0%	440 kg/s	1 MPa
C	0%	440 kg/s	1 MPa

Point A All values are given.

Point B Steam is "saturated" so moisture is 0%. 12% of moisture has been removed at point B so flowrate deceases by 12%.

Point C Same values as point B.

The next part of the question asks for the temperature of the steam leaving the reheater. This part of the exercise is done by equating the heat gained by the process steam to the heat lost by the heating steam.

Heating Steam

This is initially saturated at a pressure of 3.5 MPa and the condensate remains at the saturation temperature because there is no subcooling. If we sketch the temperature enthalpy diagram, we can see that the heat lost is the latent heat at the pressure of 3.5 MPa(a).

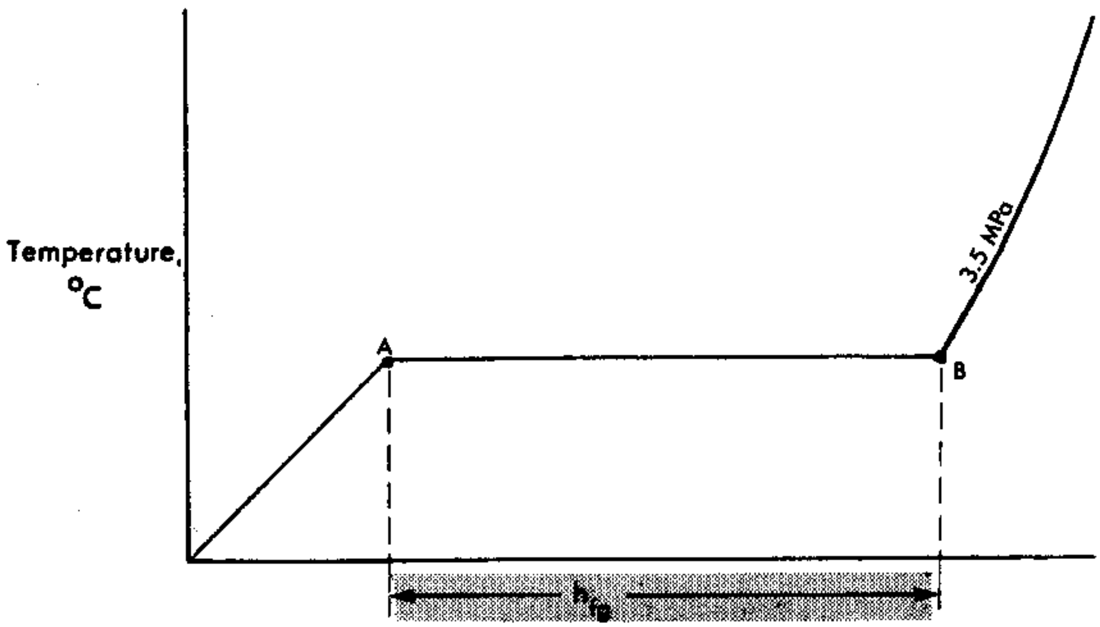


Fig. 4.9

Point A represents the saturated liquid and point B represents the saturated steam.

h_{fg} at 3.5 MPa(a) = 1752.2 kJ/kg.

The heating steam flowrate is 30.3 kg/s.

So the total heat lost is the product of the enthalpy change, 1752.2 kJ/kg and the mass flowrate, 30.3 kg/s.

Heat lost by heating steam = 1752.2 x 30.3

= 53091.7 kJ/s.

This heat is given to the process steam <u>every second</u>. In every second there are 440 kg of process steam flowing through the reheater.

So each kg of process steam picks up 1/440 of the total heat lost by the heating steam $= \frac{53091.7}{440} = \underline{120.7}$ kJ/kg.

The enthalpy of the saturated steam has been increased by 120.7 kJ/kg and we must look at the superheated steam tables to find the temperature of the steam that corresponds to this new value of enthalpy.

h_g at 1 MPa(a) = 2776.2 kJ/kg.

Enthalpy of superheated steam = 2776.2 + 120.7

= 2896.9 kJ/kg.

Using the superheated steam tables at 1 MPa we can see that at 200°C the enthalpy is 2827 kJ/kg and at 250°C the enthalpy is 2943 kJ/kg. So the temperature of the steam from the reheater is

$\frac{70}{116}$ (50°C) + 200°C = 230°C.

04.4

This is a basic arrangement of the moisture separator and reheater operating at constant pressure.

The moisture separation process will appear as a line from the 13% moisture point, on the 1 MPa(a) constant pressure line, up to the saturation line.

The reheat process will appear as a continuation along this constant pressure line up into the superheat region.

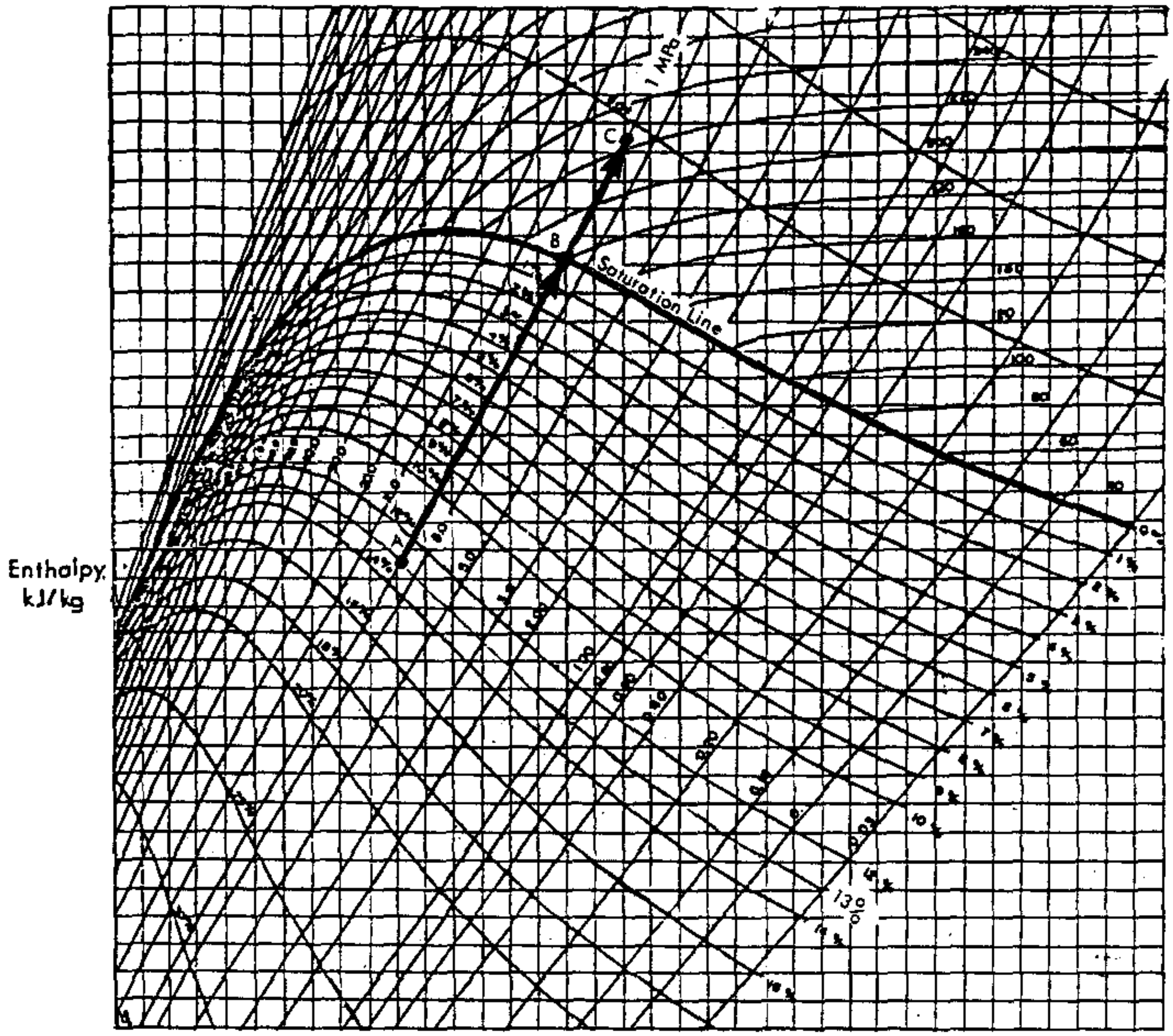


Fig. 4.10

A - B is the moisture separation process.

B - C is the reheat process.

Moisture Separation

The only changes will be the reduction in mass flowrate as the steam quality improves to saturation conditions.

Steam flow reduces to 800 x 0.87 = 696 kg/s.

Reheat

In the reheater the heat gained by the process is lost by the heating steam.

The heating steam is saturated at 3 MPa(a) and the condensate becomes subcooled by 6.8°C. So we can determine the heat lost per kg of heating steam.

h_g at 3 MPa = 2802.3 kJ/kg, t_s = 233.8°C.

The temperature of the condensate is
t_s - 6.8 = 233.8 - 6.8 = 227°C.

h_{f227} = 976.2 kJ/kg.

So the heat lost per kg of heating steam is
2802.3 - 976.2 ≐ 1826.1 kJ/kg.

The total heat lost per second is the product of the mass of heating steam per second and the enthalpy change per kg,

= 41.5 x 1826.1

= 75783 kJ.

Each kg of the process steam receives 1/696 of the heat lost by the heating steam.

1 kg of process steam receives $\frac{75783}{696}$ = 109 kJ/kg

The enthalpy of saturated steam entering the reheater at 1 MPa is 2776 kJ/kg.

The enthalpy of the superheated steam leaving the reheater at 1 MPa(a) is 2776 + 109 kJ/kg = 2885 kJ/kg.

Using the superheat steam tables at 1 MPa(a), we can find the temperature to which this enthalpy corresponds.

Enthalpy at 200°C and 1 MPa(a) = 2827 kJ/kg.
Enthalpy at 250°C and 1 MPa(a) = 2943 kJ/kg.

Difference for 50°C is 116 kJ/kg.

The enthalpy at the reheater outlet is 2885 kJ/kg which is 2885 - 2827 = 58 kJ/kg more than the enthalpy at 200°C.

Temperature increase above 200°C = $\frac{58}{116} \times 50 = 25$°C.

Steam temperature = 225°C.

Q4.5

In this problem the steam into the turbine is superheated so the entropy values for the initial steam condition will have to come from the superheated steam tables.

As in the previous question, the value of entropy remains constant during the expansion process. On the Mollier diagram the process will appear as a vertical line running down from the superheat region at 250°C and a pressure of 2 MPa to intersect the constant pressure line of 6 kPa(a).

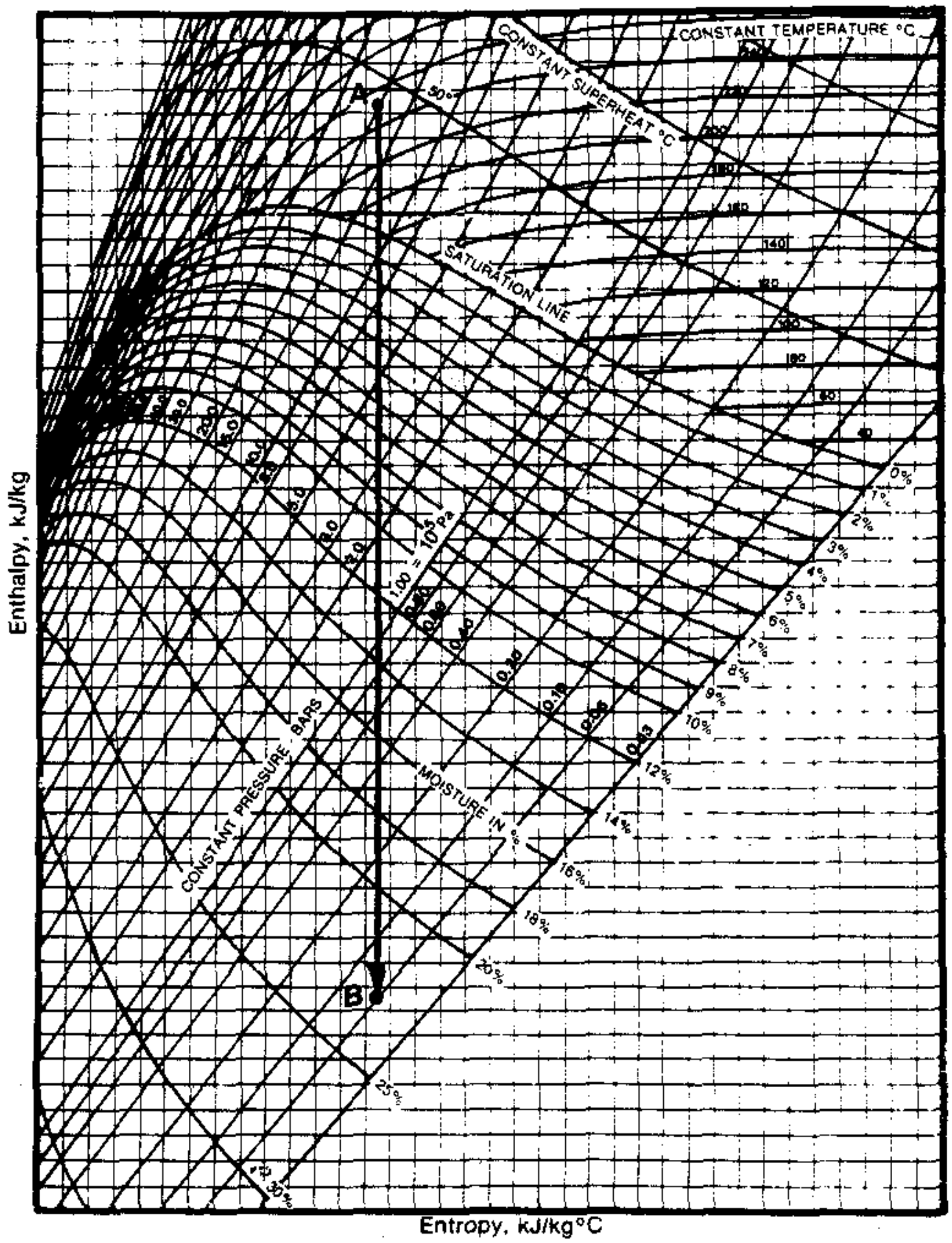


Fig. 4.11

Again we use the entropy value at the inlet condition to determine the condition of the exhaust steam.

From superheated steam tables, the value of entropy at 2 MPa(a) and 250°C is 6.545 kJ/kg°C.

At 6 kPa(a) S_f = 0.5209 kg/kg°C
S_{fg} = 7.8104 kJ/kg°C.

The entropy of the superheated steam is equal to the entropy of the wet steam after expansion.

Thus $6.545 = 0.5209 + q\,(7.8104)$

$$6.0241 = q\,(7.8104)$$

$$q = \frac{6.0241}{7.8104}$$

$$= \underline{77.1\%}.$$

So the moisture level is 23%.

Q4.6

In this startup condition, prior to the admission of steam into the turbine, the whole of the turbine unit is at the same pressure, ie, the condenser pressure of 5.6 kPa(a). From the GSV through the HP turbine, moisture separators, reheaters and low pressure turbines the pressure is the same as that in the condenser.

Q4.7

Again in this condition the whole of the turbine unit is at the condenser pressure of 10 kPa(a).

The GSVs are not isolating valves, they are control valves and are not designed to prevent total admission of steam to the HP turbine. Immediately after the GSV the pressure will have been throttled to 10 kPa(a). The throttling process will cause the steam to become superheated and its final temperature (immediately downstream of the GSVs) will be approximately 160°C.

If the turbine was recently shutdown with the turbine "hot" this throttled steam entering the hp turbine can produce severe quenching of hp turbine rotor. This problem can be avoided by ensuring that the ESV's are always shut if there is any pressure in the steam lines.

Q4.8

If you look at the conditions of temperature and flowrate in the reheater you will observe the following:

(a) Temperature of the heating steam remains constant over the whole power range (assuming constant boiler pressure).

(b) The temperature of the process steam entering the reheater, from the HP turbine via the moisture separator, rises as the turbine power increases.

The temperature difference between the heating steam and the process steam which is being heated, becomes smaller as the turbine power increases, ie, from T = 121°C at 25% load to T = 79°C at 100% load.

With a smaller temperature between the turbine steam and heating steam it would seem reasonable to suppose that the turbine steam temperature would more easily approach the heating steam temperature of 254°C.

What has changed besides the temperatures in the reheater as the load increases? The turbine steam mass flowrate has increased by approximately four times from 25% load to 100% load. This results in the process steam mass flowrate through the reheater increasing by a factor of four. The increased flowrate reduces the time that the steam is in the reheater by a factor of four. The process steam is not in the reheater long enough to be heated to the temperature of the heating steam. As the process steam flowrate increases, the difference between the heating steam temperature and turbine steam temperature at the reheater outlet, increases, due to the decreased time for heat transfer.

At 25% the difference between the heating steam temperature and the turbine steam temperature at the reheater outlet is 4°C. At 100% the difference is 15°C.